Cairo University
Faculty of Engineering
Mech. Power Department

ACC Virtual Labs
Automatic Control Circuits & Virtual Labs for Mechanical Power Systems
معمل التحكم الأوتوماتيكي و المعامل الإفتراضية لأنظمة القوى الميكانيكية

دبلوم تطبيقات التحكم الأوتوماتيكى فى نظم القوى الميكانيكية

MEP 599 Diploma Project-Fall 2020-2021

Parameter monitoring and control during petrol transportation using PLC-based PID controller

Prepared by Eng. Wael M. Ibrahim

Supervisor: Assoc. Prof. Dr. Mohsen, ACC Manager&Director of Automatic Control Diploma, Mech. Power Dept.

Overview: The project presents some extracted & compiled data from the original theoretical & experimental analysis of Priyanka.E.B et.al. (Refs.44-49) regarding various control systems/techniques used in pipe-lines. The project objective is to review, investigate & understand some aspects of these practical research subjects in order to enhance our information & knowledge in both fields of automatic control & pipe-lines.

Abstract: One of major sources of petroleum products is obtained from the sea (offshore & onshore). The major pipeline operation problem or task is maintaining constant pressure & flow rate until the extreme ends. In the above qouted studies, pressure & flow are maintained constant by using control valves depending on different pressure& flow of petrol transmitting pipe. PLC (Programmable Logical Controller) is used to regulate pressure &flow during petroleum transportation by controlling the percentage of opening of control valves & pumps respectively. The required set points for pressure & flow are obtained by using a suitable controller that regulates in a long transmitting concrete pipes. For this, a PLC based PID controller is developed and its theoretical open loop responses are identified. Above simulation and analysis studies are carried out by MATLAB/ SIMULINK platform to ensure good performance of the controller. The controller tuning is done by ZN (Ziegler and Nicholas) PID& Simple-IMC(Internal Model Control) PID, Shams tuning IMC-PID controller. The simulation result provides better control action when Shams IMC-PID controller is used. Shams IMC-PID controller is experimentally verified on the lab scale-setup and the experimental results prove that it provides most consistent performance as compared to ZN and Simple-IMC PID controllers.

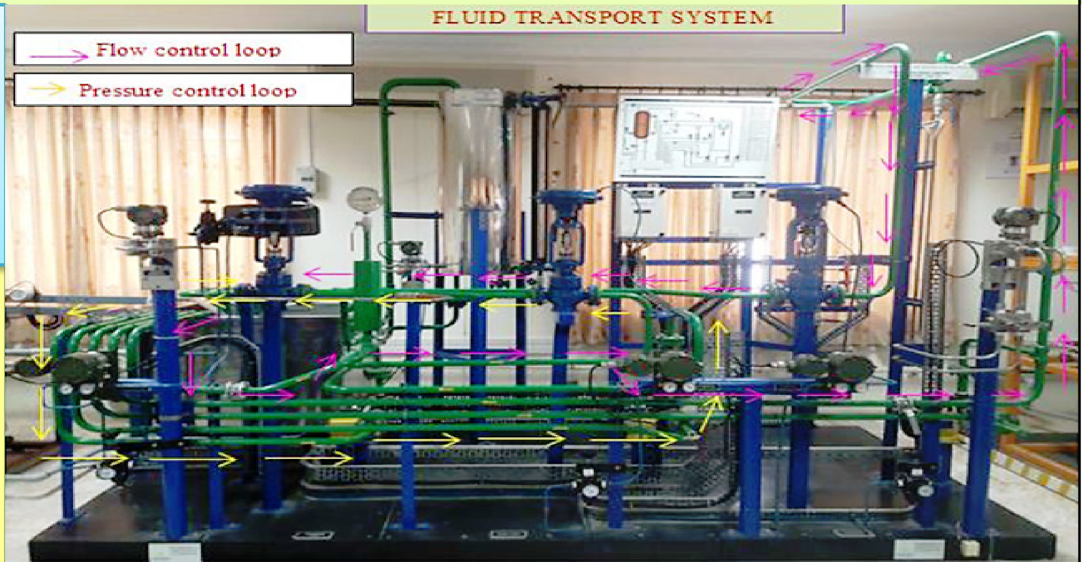
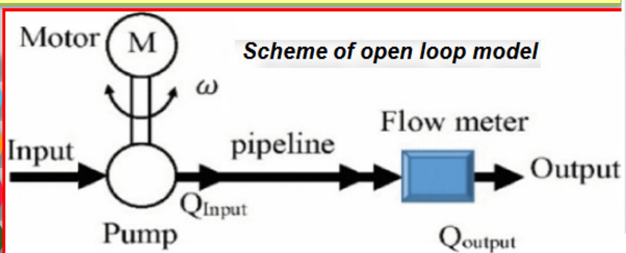


Fig. 2.The lab scale experimental setup of the fluid transport system

Contents



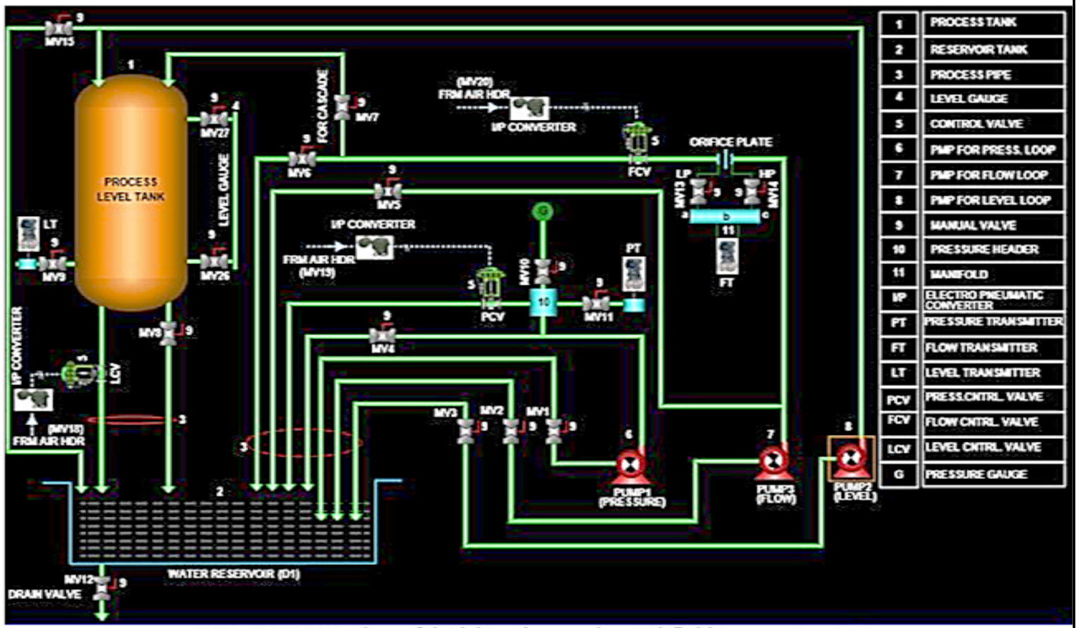
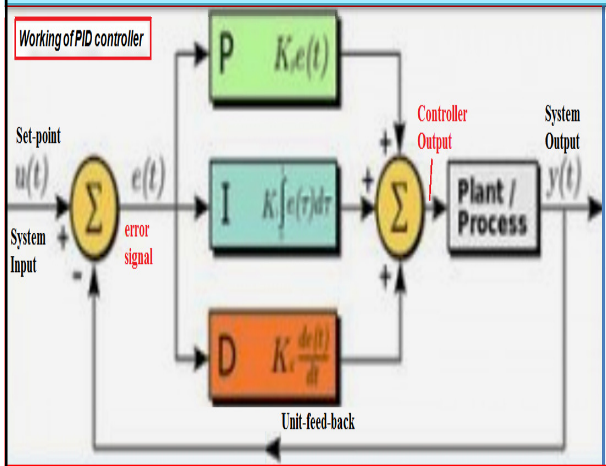
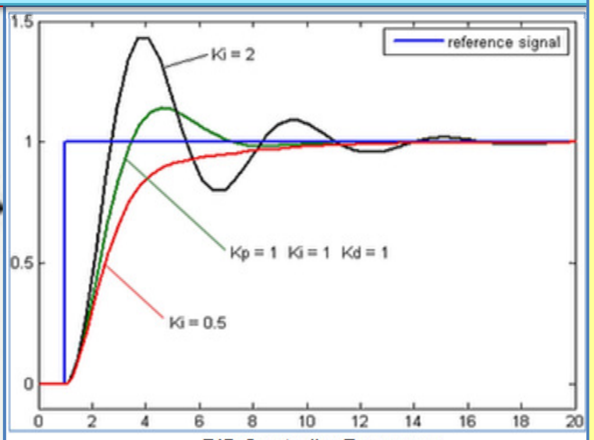


Fig. 3.SCADA view of the lab scale experimental fluid transport system

Ch(1) PID Controller Definition & Explanations (يوجدعلى موقع المعمل أيضاً عدة افلام فيديو قصيرة حول شرح هذا الموضوع)





PID Controller Response

PID Controller Working Principle: working principle behind a PID controller is that the proportional, integral and derivative terms must be individually adjusted or "tuned." Based on the difference between these values a correction factor is calculated and applied to the input. For example, if an oven is cooler than required, the heat will be increased. Here are the three steps:

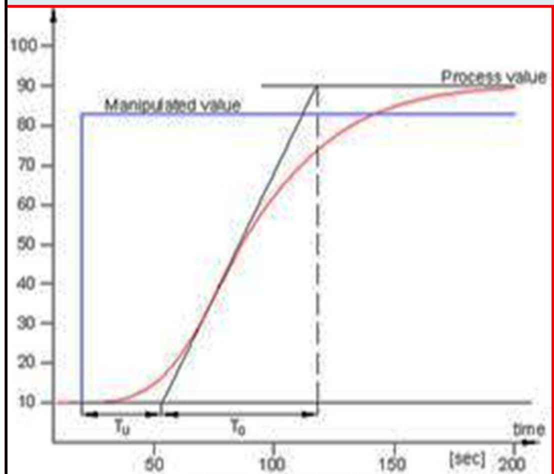
•**Proportional tuning** involves correcting a target proportional to the difference. Thus, the target value is never achieved because as the difference approaches zero, so too does the applied correction.

•**Integral tuning** attempts to remedy this by effectively cumulating the error result from the "P" action to increase the correction factor. For example, if the oven remained below temperature, “I” would act to increase the head delivered. However, rather than stop heating when the target is reached, "I" attempts to drive the cumulative error to zero, resulting in an overshoot.

•**Derivative tuning** attempts to minimize this overshoot by slowing the correction factor applied as the target approached.

Standard Type PID Controller: This kind of PID controller will merge proportional control through integral & derivative control to automatically assist the unit to compensate modifications within the system. These modifications, integral & derivative are expressed in time-based units. These controllers are also referred through their reciprocals, RATE & RESET correspondingly. The terms of PID must be adjusted separately otherwise tuned to a specific system with the trial as well as error. These controllers will offer the most precise and steady control of the three types of controller.

Real-Time PID Controllers: At present, there are various kinds of PID controllers are available in the market. These controllers are used for industrial control requirements like pressure, temperature, level, and flow. Once these parameters are controlled through PID, choices comprise utilize a separate PID controller or either PLC. These separate controllers are employed wherever one otherwise two loops are required to be checked as well as controlled otherwise in the conditions wherever it is complex to the right of entry through larger systems. These control devices provide different choices for solo & twin loop control. The standalone type PID controllers provide several fixed-point configurations to produce the autonomous several alarms.
These standalone controllers mainly comprise PID controllers from Honeywell, temperature controllers from Yokogawa, auto tune controllers from OMEGA, Siemens, and ABB controllers.
PLCs are used like PID controllers in most of the industrial control applications the arrangement of PID blocks can be done within PACs or PLCs to give superior choices for an exact PLC control. These controllers are smarter as well as powerful as compared with separate controllers. Each PLC includes the PID block within the software programming.



Process reaction curve

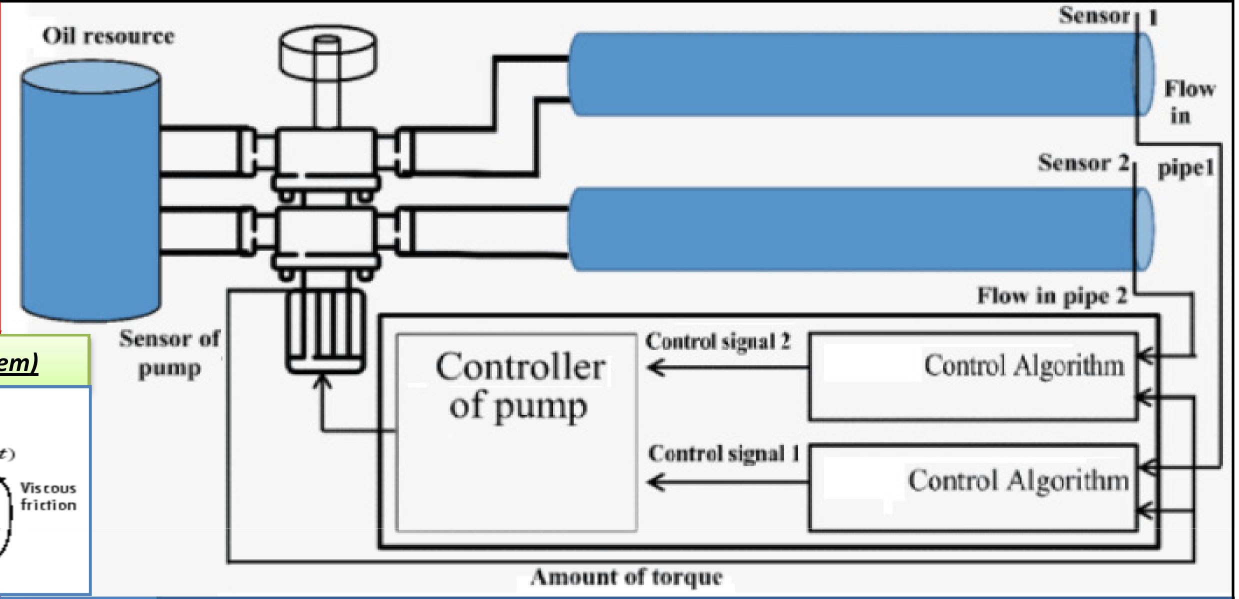
Tuning Methods Before the working of the PID controller takes place, it must be tuned to suit with dynamics of the process to be controlled. Designers give the default values for P, I, and D terms, and these values could not give the desired performance and sometimes leads to instability and slow control performances. Different types of tuning methods are developed to tune the PID controllers and require much attention from the operator to select the best values of proportional, integral, and derivative gains. Some of these are given below. PID controllers are used in most industrial applications but one should know the settings of this controller to adjust it correctly to generate the preferred output. Here, tuning is nothing but the procedure of receiving an ideal reply from the controller through setting best proportional gains, integral & derivative factors. The desired output of the PID controller can be obtained by tuning the controller. There are different techniques available to get the required output from the controller like trial &error, Zeigler-Nichols & process reaction curve. The most frequently used methods are trial & error, Zeigler-Nichols, etc.Trial and Error Method: It is a simple method of PID controller tuning. While the system or controller is working, we can tune the controller. In this method, first, we have to set Ki and Kd values to zero and increase the proportional term (Kp) until the system reaches oscillating behavior. Once it is oscillating, adjust Ki (Integral term) so that oscillations stop and finally adjust D to get a fast response. Process Reaction Curve Technique: It is an open-loop tuning technique. It produces a response when a step input is applied to the system. Initially, we have to apply some control output to the system manually and have to record the response curve. After that, we need to calculate slope, dead time, the rise time of the curve, and finally substitute these values in P, I, and D equations to get the gain values of PID terms.

Zeigler-Nichols method: **Zeigler-Nichols proposed closed-loop methods for tuning the PID controller. Those are the continuous cycling method and damped oscillation method. Procedures for both methods are the same but oscillation behavior is different. In this, first, we have to set the p-controller constant, Kp to a particular value while Ki and Kd values are zero. Proportional gain is increased until the system oscillates at a constant amplitude. Gain at which system produces constant oscillations is called ultimate gain (Ku) and the period of oscillations is called the ultimate period (Pc). Once it is reached, we can enter the values of P, I, and D in the PID controller by Zeigler-Nichols table depends on the controller used like P, PI or PID, as shown below.**

	K_c	T_I	T_D
P	$K_u/2$		
PI	$K_u/2.2$	$P_u/1.2$	
PID	$K_u/1.7$	$P_u/2$	$P_u/8$

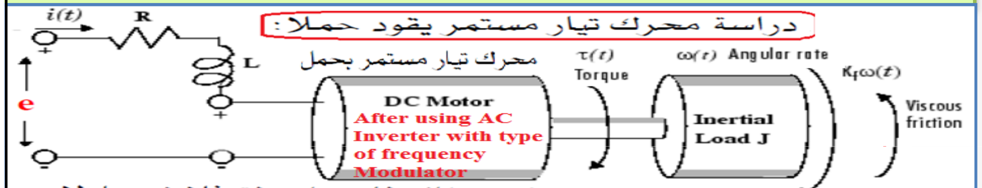
Zeigler-Nichols table

Flow-rate PID Controller: PID controller is utilized in order to control flow rate of the heavy oil in pipelines by controlling *frequency modulation of AC inverter driving the pump-motor.* A torque actuator is placed on the motor pump in order to control the rotation-speed of the pump-motor and consequently controlling the flow rates in pipelines. The necessary conditions for the asymptotic stability of the proposed controller are validated by implementing Lyapunov stability theorem. The theoretical concepts are validated utilizing numerical simulations and analysis, which proves the effectiveness of the PID controller in control of flow rates in pipelines.



Corrected Modeling of motor-pump: ***(By analogy to Mass-spring-dashpot system)***

دراسة محرك تيار مستمر يقود حملا:



يعرف هذا النظام بواسطة ثلاث معادلات:

- المعادلة الأولى: $L\dfrac{di}{dt}+Ri+K_e\Omega=e$ (1)
- المعادلة الثانية: العزم $= J\dfrac{d\Omega}{dt}+B\Omega$ (2)
- المعادلة الثالثة: عزم المحرك$= K_t i$ (3)

بدمج المعادلتين (2) و(3) نحصل على: $J\dfrac{d\Omega}{dt}+B\Omega=K_t i$

بالتعويض عن التيار نحصل على المعادلة التفاضلية: $\boxed{a_2\dfrac{d^2\Omega}{dt^2}+a_1\dfrac{d\Omega}{dt}+\Omega=Ge}$

$$a_2=\frac{\tau_m\tau_e RB}{K_eK_t+RB}\ ,\ a_1=\frac{(\tau_m+\tau_e)RB}{K_eK_t+RB}\ ,\ G=\frac{K_t}{K_eK_t+RB}$$

حيث: $\tau_m=\dfrac{J}{B}$ وهو ثابت الزمن للجزء الميكانيكي. $\tau_e=\dfrac{L}{R}$ وهو ثابت الزمن للجزء الكهربي للنظام.

J: عزم قصور الحمل $(kg.m^2)$ B: معامل الاحتكاك (N.m.s/rad) L: محاثة العضو الدوار (H)

R: مقاومة العضو الدوار (Ω) K_t: ثابت العزم (N.m/A) E: جهد الدخل (V)

ω: السرعة الزاوية للمحرك (rad/s) K_e: ثابت قوة الدفع الكهربائي (V.s/rad)

وعليه فإن معاملات محرك التيار المستمر تصبح كالتالي: $\boxed{\omega_0=\sqrt{\dfrac{1}{a_2}}\ ,\ \alpha=\dfrac{a_1}{2a_2}\ ,\ \xi=\dfrac{a_1}{2\sqrt{a_2}}}$

❖ الاستجابة الزمنية لنظام ذي المرتبة الثانية:

لندرس الاستجابة العابرة لهذا النظام عندما نطبق إشارة في شكل وحدة درجية عند مدخل النظام f(t).

ويتضح من مخطط المنظومة أن الخرج يساوي: $\Omega(s)=\dfrac{\omega_0^2/K}{s(s^2+2\xi\omega_0 s+\omega_0^2)}$

where Ω(s) is laplace transform of ω(t)

القوس في المقام له اكثرمن جذر عندعمل التحليل الجزئ

ونظرا لوجود كثير حدود من الدرجة الثانية في مقام X(S) فيمكننا أن نلاحظ ٣ حالات مختلفة لطبيعة الاستجابة الزمنية ω(t) حسب قيمة نسبة التخميد ξ. يعني أن: $\Delta=\xi^2\omega_0^2-\omega_0^2=\omega_0^2(\xi^2-1)$

أ- الحالة الأولى: $\Delta>0$ أي $\xi>1$: نظام مفرط التخميد (over damped system)

في هذه الحالة تكون جذور كثيرة الحدود: $s^2+2\xi\omega_0 s+\omega_0^2$ ، حقيقية مختلفة:

$$s_1=-\xi\omega_0-\omega_0\sqrt{\xi^2-1}=-\omega_0(\xi+\sqrt{\xi^2-1})$$

$$s_2=-\xi\omega_0+\omega_0\sqrt{\xi^2-1}=-\omega_0(\xi-\sqrt{\xi^2-1})$$

$$x(s)=\frac{\omega_0^2}{s(s-s_1)(s-s_2)}=\frac{A}{s}+\frac{B}{s-s_1}+\frac{C}{s-s_2}$$

حيث: A=1 ، $B=\dfrac{s_2}{s_1-s_2}$ ، $C=\dfrac{-s_1}{s_1-s_2}$

$$\boxed{\omega(t)=1+Be^{s_1t}+Ce^{s_2t}}$$

ب- الحالة الثانية: $\Delta=0$ أي $\xi=1$ ، نظام ذو تخميد حرج (critically damped system)

في هذه الحالة تكون جذور كثيرة الحدود: $s^2+2\xi\omega_0 s+\omega_0$ ، حقيقية ومتساوية: $s_1=s_2=-\xi\omega_0$

$$\Omega(s)=\frac{\omega_0^2}{s(s+\xi\omega_0)^2}=\frac{A}{s}+\frac{B}{s+\xi\omega_0}+\frac{C}{(s+\xi\omega_0)^2}$$

$$\boxed{\omega(t)=1-e^{-\omega_0 t}(1+\omega_0 t)}\ (\xi=1)$$

ج- الحالة الثالثة: $\Delta<0$ أي $\xi<1$ نظام ناقص التخميد (Under damped system)

في هذه الحالة تكون جذور كثيرة الحدود: $s^2+2\xi\omega_0 s+\omega 2_0$ مركبة كالتالي:

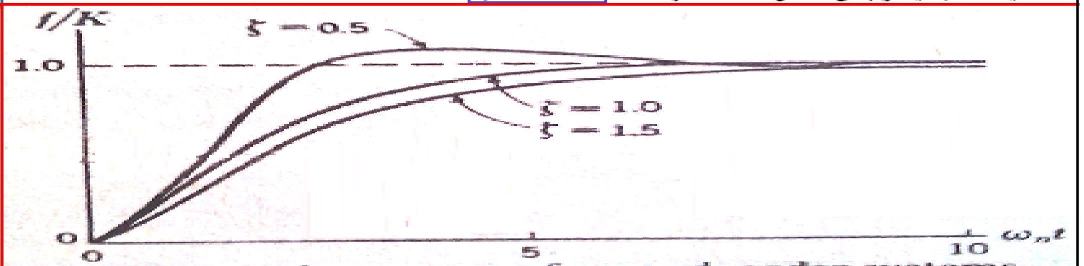
$$s_1=-\xi\omega_0+j\omega_0\sqrt{1-\xi^2}\qquad s_2=-\xi\omega_0-j\omega_0\sqrt{1-\xi^2}$$

$$\Omega(s)=\frac{\omega_0^2}{s[(s+\xi\omega_0)^2+\omega_0^2(1-\xi^2)]}=\frac{A}{s}+\frac{Bs+c}{(s+\xi\omega_0)^2+\omega_0^2(1-\xi^2)}$$

$$\boxed{\omega(t)=1-\frac{1}{\sqrt{1-\xi^2}}e^{-\omega_0 t}.\sin[\sqrt{1-\xi^2}\,\omega_0 t+Q]}\qquad(\xi<1)$$

حيث: $Q=arctg\dfrac{\sqrt{1-\xi^2}}{\xi}$ وتعتبر هذه الحالة الأكثر أهمية من أنظمة التحكم وتتميز الاستجابة الدرجية *unit step input* في هذه الحالة بمواصفات منها:

- زمن الصعود (t_r): وهو الزمن اللازم للاستجابة كي تصعد من 0 إلى 100 % من القيمة النهائية ويمكن استنتاجه من العلاقة: $\boxed{t_r=\dfrac{\pi-Q}{\omega_0\sqrt{1-\xi^2}}}$
- ذروة التجاوز (M_p)، وهي أكبر قيمة تتجاوز بها الاستجابة القيمة النهائية وهي كالتالي: $\boxed{M_p=e^{\frac{-\pi\varsigma}{\sqrt{1-\xi^2}}}}$
- زمن ذروة التجاوز (t_p): وهو الزمن الموافق لذروة التجاوز ويحسب من العلاقة: $\boxed{t_p=\dfrac{\pi}{\omega_0\sqrt{1-\xi^2}}}$
- زمن السكون (t_s)، وهو الزمن الذي تصل فيه الاستجابة إلى قيمة داخل ظرف ±5% حول القيمة النهائية وتبقى داخل هذا الظرف: $\boxed{t_s=3/\xi\omega_0}$



Mathematical response of second- order systems with step inputs.

Materials and Methods for Modelling of the System

Flow control loop system is a feedback control system. The structure of the pump model system is shown in Figure, which is an open loop system. If there is unwanted vibration in the motor, the stability of the flow rate will hamper. Therefore, it is important to change the open loop system to a closed loop system by implementing a controller to control the stability of flow rate by controlling the vibration in the motor.

Scheme of open loop model

Modelling of the Pipeline

The proposed model consists of induction motor, which causes a rotation in pump and consequently can lead to flow of heavy-oil in pipelines as shown this flow model can be illustrated in the form of partial differential equation. From the viewpoint of incompressible, constant-density, constant-viscosity flows associated with Newtonian fluids, the nonlinear Navier–Stokes equation is defined for a non-dimensional velocity field

$(x, t) : \mathbb{R}^n \times R \rightarrow \mathbb{R}^n$, pressure field $p(x, t) : \mathbb{R}^n \times R \rightarrow \mathbb{R}^n$ and Reynolds number $Re > 0$ as below equation,

$$\frac{\partial u}{\partial t} = -\frac{\nabla p}{\rho} - u.\nabla u + F_f \quad (1)$$

where,

ρ is the density in $\frac{kg}{m^3}$

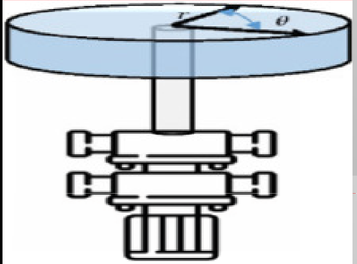
u is the flow velocity in $\frac{m}{s}$

∇ is the divergence,

p is the pressure in $\frac{kg}{m.s^2}$,

t is time in s,

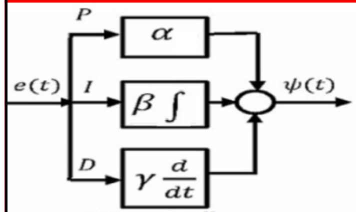
F_f is termed as the summation of external force and body forces



Torsional actuator with motor-pump arrangement

Modeling of the Actuator

In order to reduce the vibrations of the motor caused by the external forces (fp) a torsional actuator is placed on the motor. The motor and the pump are interconnected with the help of a shaft. The main purpose of the motor is to drive the pump. The pump with the help of the motor initiate a flow of fluid in the pipe. Any unwanted vibration in the motor will result in the vibration in the pump, which will result in improper flows in the pipe.

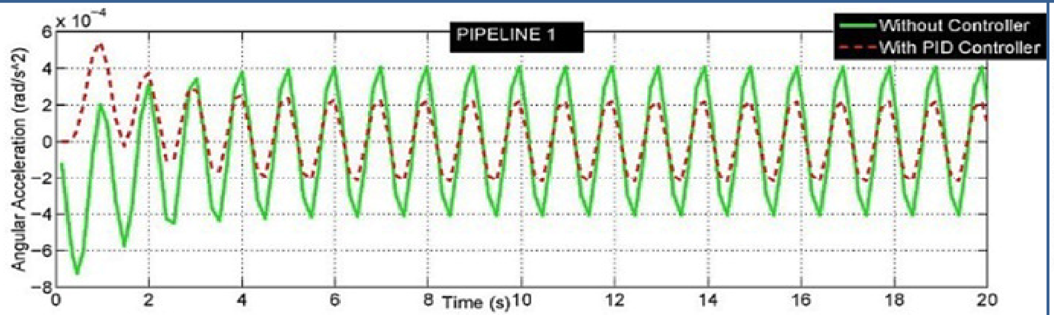


PID controller.

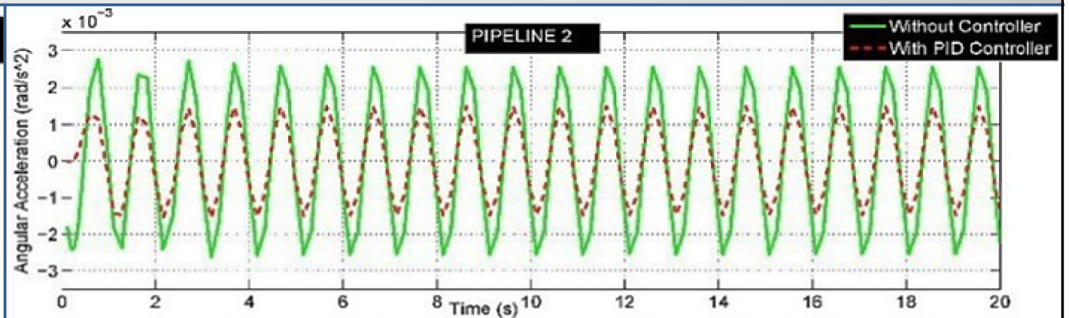
The Tuning Method Based on PID Controller

Since 1700's the control of continuous process has been carried out by utilizing feedback loop. System with feedback control contains drawback, which is related to the instability of the system. In order to resolve this problem an appropriate controller should be chosen and it must be ideal for the monitoring system. The proportional feedback control is uncomplicated and relatively easy to implement. Nevertheless, its outcome is completely sensitive to the sensing location as well as feedback gain.

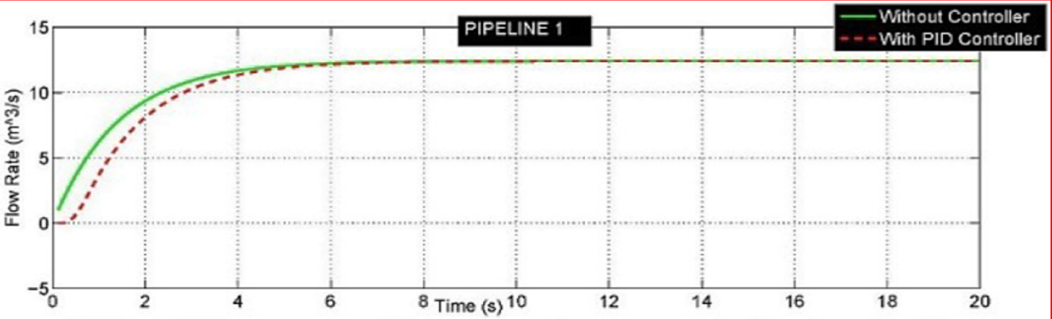
Two subsystem blocks of model, one in the absence of control mechanism as open loop system and another with control mechanism are generated for comparing the outcomes. The flow rate from the pump is the input to the flow model. Numerical integrators are utilized in order to calculate the velocity as well as the position from the acceleration signal. The control signal from the controller subsystem block is given to the Torsional actuator simulation block in order to produce the essential control forces.



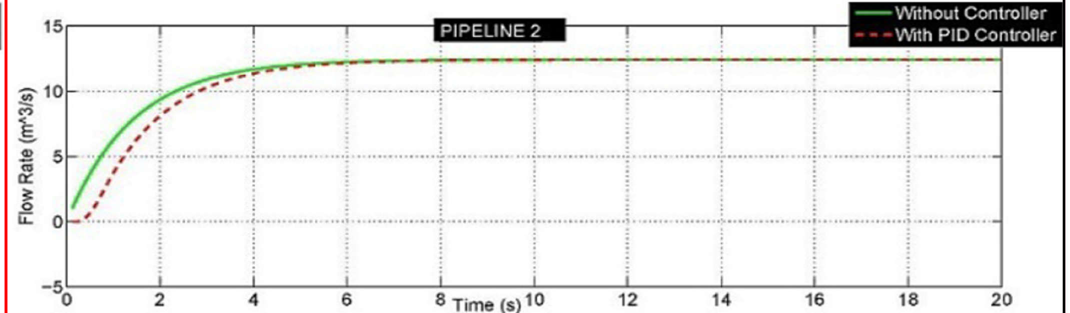
Comparison of motor vibration attenuation using PID controller for pipeline 1.



Comparison of motor vibration attenuation using PID controller for pipeline 2.



Stability of flow rate with using of PID controller in pipeline 1.



Stability of flow rate with using of PID controller in pipeline 2.

PID Controller System Design

Effects of Proportional, Integral and Derivative Action

Proportional control is illustrated with $T_i = \infty$ and $T_d = 0$. The figure shows that there is always a steady state error in proportional control. The error will decrease with increasing gain, but the tendency towards oscillation will also increase.

Figure illustrates the effects of adding integral that the strength of integral action increases with decreasing integral time T_i. The figure shows that the steady state error disappears when integral action is used. The tendency for oscillation also increases with decreasing T_i. The properties of derivative action are illustrated in diagram which illustrates the effects of adding derivative action. The parameters K and T_i are chosen so that the closed-loop system is oscillatory.

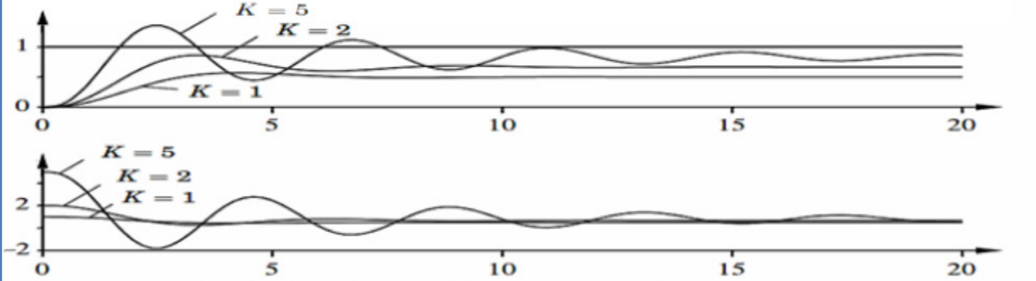


Figure 6.1 Simulation of a closed-loop system with proportional control. The process transfer function is $P(s) = 1/(s+1)^3$.

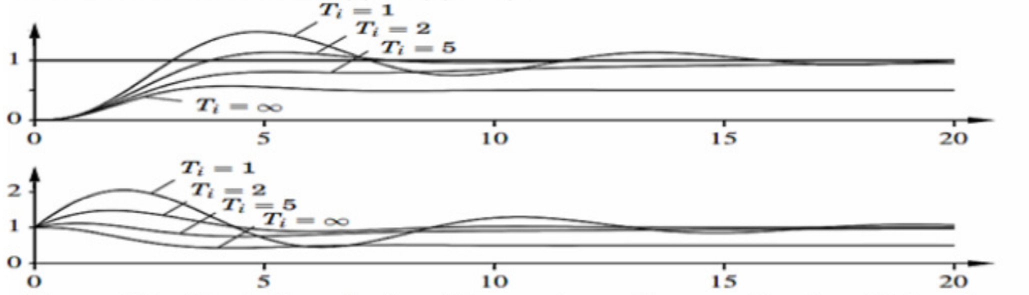


Figure 6.2 Simulation of a closed-loop system with proportional and integral control. The process transfer function is $P(s) = 1/(s+1)^3$, and the controller gain is $K = 1$.

A Perspective

There is much more to PID than is revealed. A faithful implementation of the equation will actually not result in a good controller. To obtain a good PID controller it is also necessary to consider.

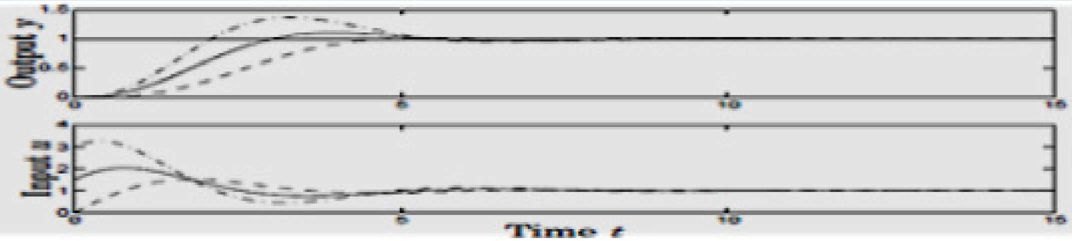
- Noise filtering and high frequency roll-off
- Windup
- Computer implementation
- Set point weighting and 2 DOF
- Tuning

Differentiation is always sensitive to noise this is clearly seen from the transfer function $G(s) = s$ of a differentiator, which goes to infinity for large s the following example is also illuminating. Differentiation amplifies high frequency noise consider the signal

$$y(t) = \sin t + n(t) = \sin t + a_n \sin \omega_n t \qquad \frac{dy(t)}{dt} = \cos t + n(t) = \cos t + a_n \omega \cos \omega_n t$$

where the noise is sinusoidal noise with frequency w. The derivative of the signal is shown above This ratio can be arbitrarily high if w is large in a practical controller with derivative action it is therefore necessary to limit the high frequency gain of the derivative term. This can be done by implementing the derivative term as

$$D = -\frac{sKT_d}{1 + sT_d/N} Y$$



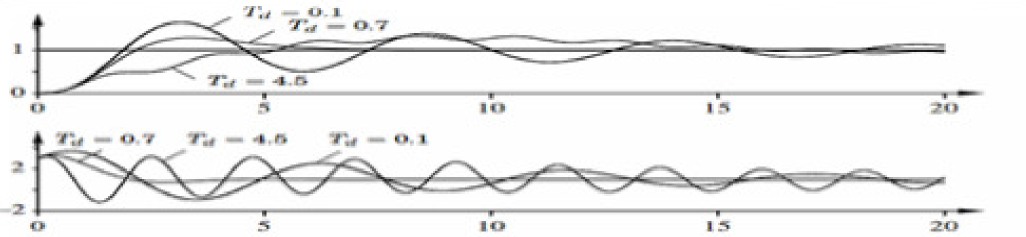


Figure 6.3 Simulation of a closed-loop system with proportional, integral and derivative control. The process transfer function is $P(s) = 1/(s+1)^3$, the controller gain is $K = 3$, and the integral time is $T_i = 2$.

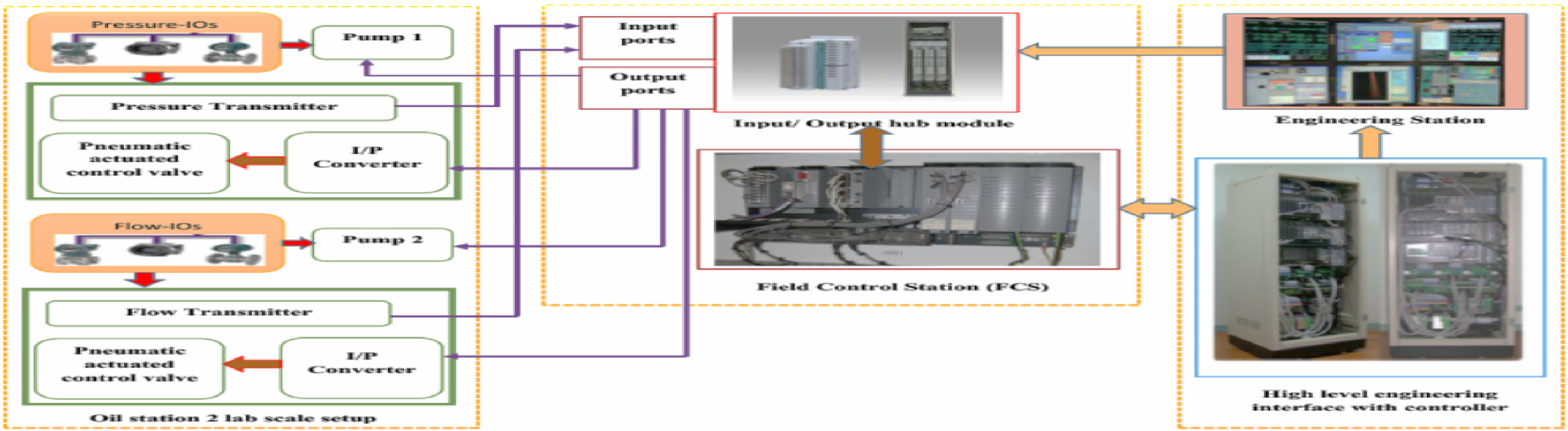


Fig. 1.Block diagram with local intelligence for the process plant.

The controller structure of the PID block for the fluid transportation system to monitor pressure and flow rate is developed using SIMULINK in MATLAB platform is presented.

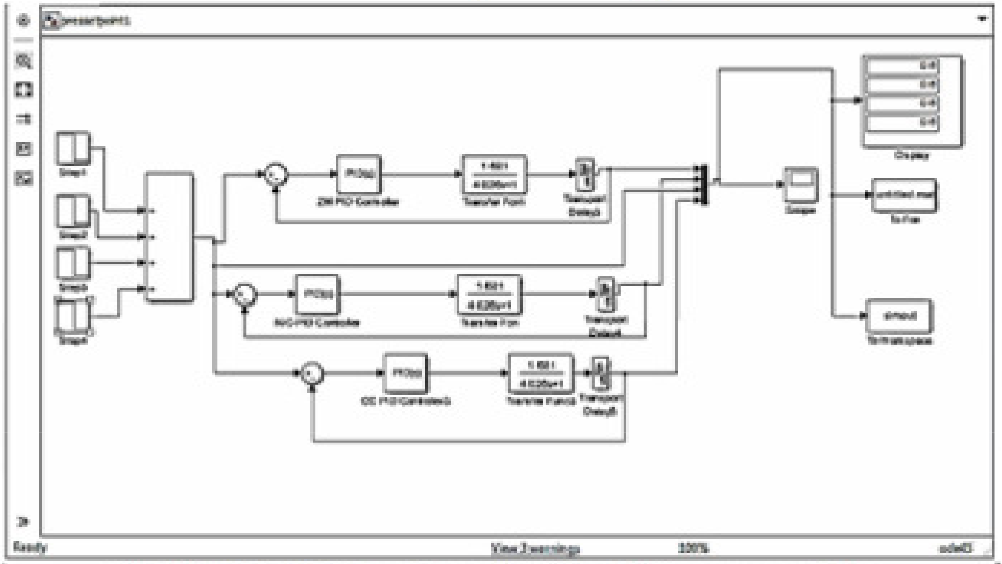


Fig. 7. MATLAB platform based created Simulink model for pressure control loop

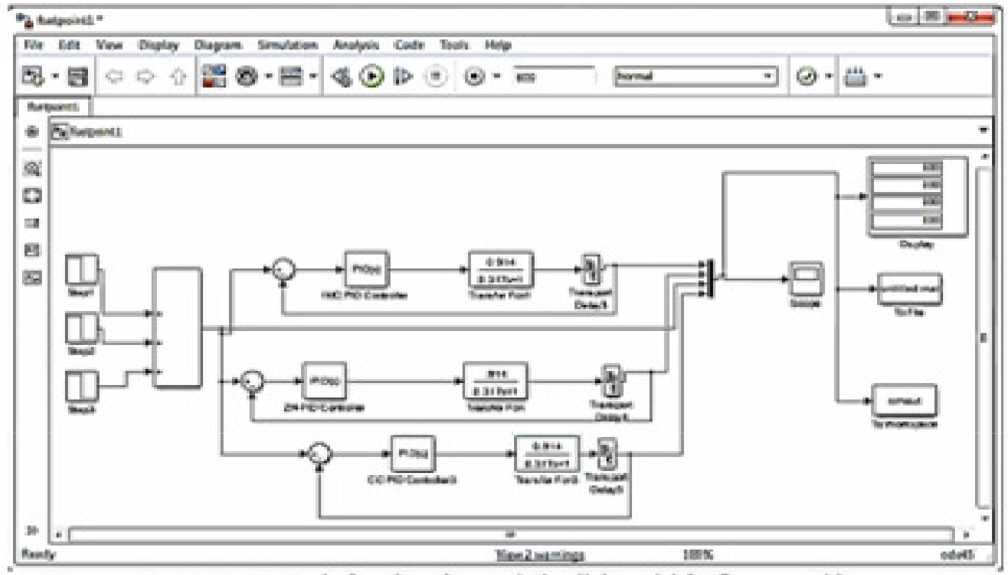


Fig. 8 MATLAB platform based created Simulink model for flow control loop

Disturbance rejection test for pressure and flow control loop

The disturbance rejection performance is investigated at the operating point of pressure at 2.1Kg/Cm² and flow rate at 1300 lph. A step disturbance is introduced into the process by way of increasing the pressure to 3Kg/Cm² and flow rate to 1600 lph after the time period of 100 and 150 seconds as shown. As of the analysis, result endorses the merit by pointing only IMC-PID controller damp the disturbance in a smaller time period of 13 seconds with less undershoot of 11.33% as compared to the CC-PID and ZN-PID PID controllers on pressure control loop.

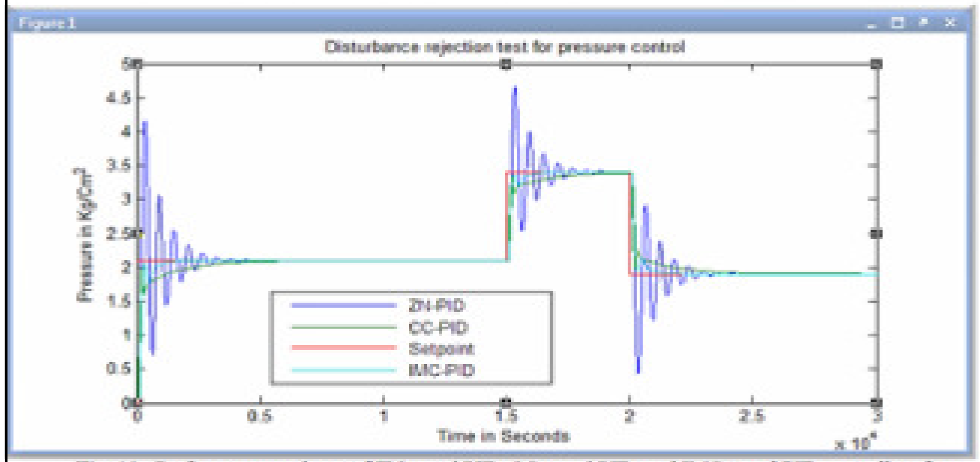
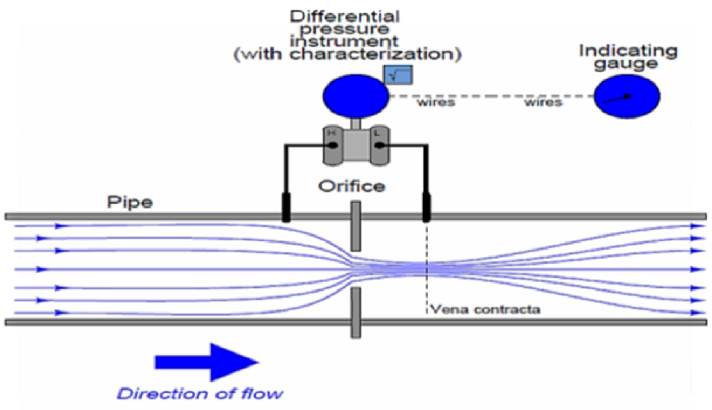


Fig. 12a.Performance analyses of ZN tuned PID, CC tuned PID, and IMC tuned PID controllers for pressure control loop after a disturbance at a set point of 2.1Kg/Cm²

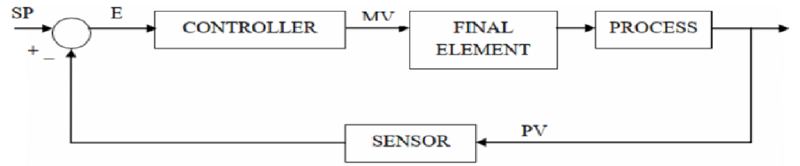
Fig. 12b Performance analyses of ZN tuned PID, CC tuned PID, and IMC tuned PID controllers for flow control loop after a disturbance at a set point of 1300 lph.



DP Transmitter Structure

Table 2: Type of Flow Transmitter

Flow measurement technology	Operating principle	Linearity
Differential pressure	Fluid mass self-acceleration Potential kinetic energy exchange	$\sqrt{\Delta P}$
Vortex	von Karman effect	Linear
Coriolis	Fluid Inertia, coriolis effect	Linear



Negative Feedback Closed Loop

Closed loop system

In process control, closed loop system is used in order to make a system to be in automatic mode. The automatic mode means, the value of a process variable (PV) - measured by sensor will be continuously feedback to the system input which the value is compared with a desired set point (SP). The difference between process variable and set point is known as error (E). Controller function as an error compensator which the error will be reduce until PV= SP. A signal called manipulated variable (MV) is send to final element in order to control the process.

Real-time experimentation of local intelligence on fluid transport system

The proposed local intelligence using IMC-PID controller design performance is experimentally substantiated in real-time on lab-scale experimental set up of the fluid transport system. The control drawing for the process plant architecture is developed by creating two separate control loop blocks of PID controller for pressure and flow rate as shown.

The process plant is starting to run by enabling the auto mode initiated by the local intelligence, when the fixed operating point for flow rate and its pressure is given in the corresponding monitoring particular field parameters faceplate present in SCADA front-end panel of the fluid transport system.